

LANE RECOGNITION APPARATUS FOR VEHICLE

BACKGROUND OF THE INVENTION

5 The present invention relates to an apparatus for recognizing a lane on which a vehicle or other mover travels.

Various lane recognition apparatuses have been proposed in order to assist a driver to drive a vehicle along a lane or to automatically drive a vehicle. Japanese Patent Provisional Publication No. 11-259639
10 discloses a lane recognition apparatus which is capable of determining whether each of the detected lane marker candidate point may be treated as a correct candidate point, on the basis of the dispersion of lane marker candidate points and an estimated line.

15 SUMMARY OF THE INVENTION

However, such a lane recognition apparatus yet has problems to be improved in order to further accurately and stably estimate a road shape.

It is therefore an object of the present invention
20 to provide an improved lane recognition apparatus which is capable of eliminating an erroneous recognition caused by an erroneous detection of lane marker candidate points.

An aspect of the present invention resides in a lane recognition apparatus for a vehicle, which comprises an
25 image picking-up section picking up a road image ahead of the vehicle; a lane-marker detecting section detecting a plurality of lane-marker candidate points on the road image; a road model parameter calculating section calculating a road model parameter representative of a
30 road shape ahead of the vehicle on the basis of the lane-marker candidate points; a deviation calculating section calculating a deviation between the lane marker

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candidate point and an estimated candidate point
estimated from the road model parameter; and a lane
marker detection feasibility determining section
determining whether the road image is employed for
5 detecting the lane marker, on the basis of the deviation.

Another aspect of the present invention resides in a
method for recognizing a lane ahead of a vehicle, which
method comprises a step for picking up a road image ahead
of the vehicle; a step for detecting a plurality of lane
10 marker candidate points from the road image; a step for
calculating a road model parameter representative of a
road shape ahead of the vehicle on the basis of the lane
marker candidate points; a step for calculating a
deviation between the lane marker candidate point and an
15 estimated candidate point estimated from the road model
parameter; and a step for determining whether the road
image is employed for detecting the lane marker, on the
basis of the detecting deviation.

Further another aspect of the present invention
20 resides in a lane recognition apparatus for a vehicle
which comprises a camera and a processor. The camera is
installed to the vehicle and picks up a road image ahead
of the vehicle. The processor is coupled to the camera
and is arranged to detect a plurality of lane marker
25 candidate points from the road image, to calculate a road
model parameter representative of a road shape ahead of
the vehicle on the basis of the lane marker candidate
points, to calculate a deviation between the lane marker
candidate point and an estimated candidate point
30 estimated from the road model parameter, and to determine
whether the road image is employed for detecting the lane
marker, on the basis of the deviation.

The other objects and features of this invention will become understood from the following description with reference to the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

5 Fig. 1 is a block diagram showing a lane recognition apparatus which is common in first to third embodiments according to the present invention.

 Fig. 2 is a flowchart showing a processing procedure of the lane recognition apparatus of the first embodiment.

10 Fig. 3 is a flowchart showing a processing procedure of the lane recognition apparatus of a second embodiment.

 Fig. 4 is a flowchart showing a processing procedure of the lane recognition apparatus of a third embodiment.

15 Fig. 5 is a view showing a relationship between a road coordinate system and a plane coordinate system employed in the present invention.

 Figs. 6A and 6B are views showing a road model according to the present invention.

20 Fig. 7 is an explanatory view of lane marker detection small areas employed in the present invention.

 Fig. 8 is an explanatory view of a lane marker detection result and a lane marker candidate point.

 Fig. 9 is a view showing a relationship between the lane marker candidate points and an estimated road model.

25 Fig. 10 is an explanatory view of a deviation between the estimated candidate point and the lane marker candidate point.

 Fig. 11 is a graph showing a detectable threshold between detectable data and undetectable data.

30 Figs. 12A is a view showing an example of a lane marker detectable image, and Fig. 12B is a view showing an example of a lane marker undetectable image.

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DETAILED DESCRIPTION OF THE INVENTION

Embodiments of the invention will now be described based on the drawings.

[First Embodiment]

5 Fig. 1 is a block diagram showing a first embodiment of a lane recognition apparatus 1 for a vehicle according to the present invention. Lane recognition apparatus 1 comprises a CCD camera 101 for picking up an image of a scene of a road ahead of the vehicle, a pre-process section 102 for uniformly
10 processing an entire screen of a video signal from CCD camera 101, a lane marker detection small area setting section 103 for setting a plurality of small areas for detecting a lane marker on an input screen, a lane marker
15 detecting section 104 for detecting a part of the lane marker in each small area as a lane marker candidate point, a road parameter calculating section 105 for calculating road parameters for representing the shape of the road ahead of the vehicle based on the result of lane
20 marker detection executed at lane marker detecting section 104, a deviation calculating section 106 for calculating a deviation between the lane marker candidate point and the estimated candidate point estimated from the road model parameter, and a marker detection
25 feasibility determining section 107 for determining whether or not the lane maker can be detected from the image on the basis of deviation calculating section 106. CCD camera 101 functions as an image pickup section of the invention.

30 The lane recognition apparatus 1 comprises a processor 100 which is constituted by a microcomputer and which is coupled to CCD camera 101. The microcomputer is arranged to store the sections 101 through 107 of the

lane recognition apparatus in the form of software and to perform the processes of the sections 101 through 107 by executing a program control in processor 100.

Now, there will be described steps for recognizing a lane executed by lane recognition apparatus 1 according to the present invention.

Fig. 2 is a flowchart showing a flow of processes in the first embodiment according to the present invention. First, lane recognition apparatus 1 is started when a switch is operated by the driver or the vehicle is ignited at step S201. At step S202 road parameters for recognizing the shape of a road ahead of the vehicle are initialized.

The road parameters are defined according to the following procedure. As shown in Fig. 5, a road coordinate system is defined as an XYZ system in which the center of an image pickup lens of CCD camera 101 is the origin. The X-axis extends from the right to the left as viewed in the traveling direction of the vehicle. The Y-axis extends upward in the direction of the height of the vehicle. The Z-axis is the optical axis of the lens along the traveling direction of the vehicle. As shown in Fig. 5, a plane coordinate system of an image processing screen is defined in which the origin is at the upper left corner of the screen. The x-axis horizontally extends, and the y-axis vertically extends from the top to the bottom in accordance with the direction in which a screen is scanned in television communication systems such as NTSC.

The relationship between those two coordinate systems is as shown in Fig. 5 and, for simplicity, coordinate transformation from the road coordinate system to the plane coordinate system is expressed by Equations

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(1) and (2) shown below where the origin of the plane coordinate system is located on the Z-axis of the road coordinate system as shown in Fig. 5.

$$x = -fX/Z \quad \text{---(1)}$$

$$y = -fY/Z \quad \text{---(2)}$$

where f represents a parameter that represents the focal length of the lens.

While a planar structure of a road is defined by straight lines, curves having constant curvatures, and clothoid curves having constant curvature change rates for connecting the straight line and the curve, a section of the road of several tens meters ahead of a vehicle can be regarded as a curved road having a constant curvature or a straight road. Then, the shape of a lane marker was formulated as shown in Fig. 6A. Similarly, a longitudinal structure of the same was formulated as shown in Fig. 6B because it can be regarded as having a constant gradient. The formulae are respectively given as Equations (3) and (4) below.

$$X = \frac{\rho}{2} Z^2 + \phi Z + Y_c - iW \quad \text{---(3)}$$

$$Y = \eta Z - h \quad \text{---(4)}$$

where ρ represents the curvature of the road; ϕ represents a yaw angle of the vehicle to the road; Y_c represents lateral displacement of the vehicle from a left lane marker; W represents the vehicle width; i represents the left line marker when it is 0 and represents a right lane marker when it is 1; η represents a pitch angle of the optical axis of the lens to the road surface; and h represents the height of the camera above the ground.

The shape of a lane marker projected on the plane coordinate system of the image processing screen can be formulated from Equations (1) through (4). Equations (1)

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through (4) can be rearranged by eliminating X, Y, and Z to obtain the following Equations (5) through (10).

$$x = (a + ie)(y - d) - \frac{b}{y - d} + c \quad \text{---(5)}$$

where $a = -y_c/h,$ ---(6)

5 $b = -f^2 h \rho / h,$ ---(7)

$c = -f\phi + c_0,$ ---(8)

$d = -f\eta + d_0,$ and ---(9)

$e = W/h.$ ---(10)

10 The terms c_0 and d_0 are correction values that are required because the actual origin is located at the upper left corner of the image processing screen in spite of the fact that the origin of the plane coordinate system is on the Z-axis in the road coordinate system in Fig. 5.

15 It is apparent from the above that the curvature of the road, the pitch angle and the yaw angle of the vehicle, and the lateral displacement of the vehicle within the lane can be estimated by identifying values of parameters a through e in Equation (5) which are
20 satisfied by a lane marker candidate point detected through the image processing.

Returning to Fig. 2, at step S203, an image signal of an image picked up by CCD camera 101 is inputted to pre-processing section 102 which performs a pre-process
25 on the same. For example, as a pre-process for detecting a lane marker, primary space differentiation is performed with a Sobel Filter to emphasize a boundary between the lane marker and a road surface. The object of lane marker detection is such a boundary. Since a lane marker
30 has regions which are nearly horizontal and regions which are nearly vertical depending on the curvature of the road, two edge images are created using horizontal

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differentiation and vertical differentiation. Other edge emphasizing filters may be used to emphasize a boundary between the lane marker and road surface. Further, any method for emphasizing the boundary may be employed for
5 characteristically extracting the lane marker.

At step S204, a plurality of small areas are set in order to detect a lane marker which indicates the lane in which the vehicle is traveling on the screen. As shown in Fig. 7, the detection areas are set as predetermined
10 sections defined along the shape of the road identified from the results of the previous image processing or road parameters which have been initially set. Since road model parameter calculating section 105 comprises a storage device for storing the road model parameter, at
15 this step S204 processor 100 reads the road model parameter stored in the storage device and uses in the small area setting process.

At step S205, processor 100 detects a straight line, which most likely seems to be a boundary between the lane
20 marker and the road surface in the region in the small areas set in step S204, and defines the point on the straight line as a lane marker candidate point. As shown in Fig. 8, the upper-most point of the results of the straight line detection is defined as the lane marker
25 candidate point. Each lane marker point is stored in the form of the coordinate value in the x-y coordinate system.

At step S206, processor 100 calculates a deviation of each lane marker candidate point detected at step S205 relative to the road model estimated from the result of
30 the previous lane marker recognition result, as shown in Fig. 9. By defining such that a point, which is located on the road model and on the same y-coordinate of the lane marker candidate point treated as a calculated

object, is an estimated candidate point and that a
x-coordinate of the lane marker candidate point is q_i and
a x-coordinate of the estimated candidate point is r_i as
shown in Fig. 10, the deviation p_i is obtained by

5 Equation (11).

$$p_i = |q_i - r_i| \quad \text{---(11)}$$

Since the deviation at each lane marker candidate
point detected can be calculated by Equation (11), an
average of the respective deviations p_i is represented by
10 Equation (12) and is used as a deviation p of the lane
marker detection result in the present image.

$$p = (\text{total of all } p_i) / (\text{number of lane marker candidate points})$$

---(12)

15 Equation (13) may be employed for the calculation
of each deviation p_i as follows.

$$p_i = (q_i - r_i)^2 \quad \text{---(13)}$$

The model parameter is also read from the storage
device of the road parameter calculating section 105 and
20 used in this deviation calculating process.

At step S207, on the basis of the deviation p
calculated at step S206, it is determined whether or not
it is possible to detect the lane marker from the
inputted image. That is, marker detection feasibility
25 determining section 107 of processor 100 determines
whether the road image can be employed for detecting the
lane marker. When a condition that the value of the
average deviation p obtained from Equation (12) is
greater than or equal to a predetermined value, is
30 continuously maintained for a predetermined time period,
it is determined that it is not possible to detect the
lane marker from the input image. Further, when filtered
data, which is obtained by treating time-series data of

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the average deviation p using a low pass filter, is greater than a predetermined detectable threshold as shown in Fig. 11, it may be determined that it is impossible to detect the lane marker from the input image.

5 Figs. 12A and 12B show input images which is determined whether the lane marker is detected from the input images by using the method shown in Fig. 11. Fig. 12A shows an input image from which the lane marker can be detected, and Fig. 12B shows an input image from which the lane
10 marker cannot be detected. That is, when a film of rainwater is formed on a road surface during raining at night, reflection of roadway lighting or water stayed in trails of vehicles is picked up like as a lane marker, and therefore the erroneous detection is executed as
15 shown in Fig. 12B. In Fig. 12B, the reflection of roadway lighting is picked up as vertical lines in a left hand side image, and the water stayed in trails is picked up as a right hand side. Accordingly, Fig. 12B shows a condition that the detection result is erroneous,
20 since these reflection and water are picked up like as a lane marker.

When it is determined at step S207 that it is not possible to detect the lane marker from the input image, the program returns to step S202 and repeats the
25 above-discussed processing. When it is determined at step S207 that it is possible to detect the lane marker from the input image, the program proceeds to step S208.

At step S208, processor 100 calculates parameters for the road model from the positions of the lane marker
30 candidate points on the screen obtained at step S205. At this time, processor 100 reads the road parameter stored in the storage device of road parameter calculating section 105. An extended Kalman filter may be used as

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means for estimating an equation for a two-dimensional road model based on a result of detection of a lane marker candidate point through image processing.

Equation (14) is derived from the above-described Equations (1) through (4). Equation (14) is used as an output equation in configuring the extended Kalman filter, and the value of an x-coordinate at a y-coordinate value defined on a plane under image processing is calculated from the road curvature and a state quantity of the vehicle.

$$x = \left(-\frac{y_c}{h} + i\frac{W}{h}\right)(y + f\eta) + \frac{f^2 h \rho}{2(y + f\eta)} - f\phi \quad \text{---(14)}$$

The estimated state quantity in the extended Kalman filter includes lateral displacement y_c of the vehicle, road curvature ρ , vehicle yaw angle ϕ of the vehicle, pitch angle η of the vehicle, and height h of CCD camera 101. Further, the focal length f of the lens and the lane width W are treated as constant values. A state equation expressed as Equation (15) shown below is obtained if it is defined as a random walk model in a discrete system which is driven by white Gaussian noises v on the assumption that a change of each estimated state quantity behaves stochastically.

$$\begin{bmatrix} y_c \\ \rho \\ \phi \\ \eta \\ h \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} y_c \\ \rho \\ \phi \\ \eta \\ h \end{bmatrix} + \begin{bmatrix} 1 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} v_{y_c} \\ v_{\rho} \\ v_{\phi} \\ v_{\eta} \\ v_h \end{bmatrix} \quad \text{---(15)}$$

When State Equation (15) and Output Equation (14) are simplified into Equations (16) and (17) shown below, the extended Kalman filter is configured by Equations (18) through (21).

$$x_s(k+1) = A_s x_s(k) + G_s v(k) \quad \text{---(16)}$$

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$$x = g(x_s, y) \quad \text{---(17)}$$

$$\hat{x}_s(k+1 | k) = A_s \hat{x}_s(k | k-1) + K(k) \{x(k) - g(\hat{x}_s(k | k-1), y(k))\} \quad \text{---(18)}$$

$$K(k) = A_s P(k) C^T (C P(k) C^T + R)^{-1} \quad \text{---(19)}$$

$$P(k+1) = A_s M(k) A_s^T + G_s Q G_s^T \quad \text{---(20)}$$

$$M(k) = P(k) \{I - C^T (C P(k) C^T + R)^{-1} C P(k)\} \quad \text{---(21)}$$

where $M(k)$ represents covariance of states which is determined by the process; $P(k)$ represents covariance of later states obtained from observed values; $K(k)$ represents the gain of the Kalman filter; Q represents covariance of observation noises; R represents covariance of process noises; I represents a unit matrix; k represents a lag; and $C \equiv \frac{\partial g(\hat{x}_s(k), y(k))}{\partial x_s}$.

Although in the above embodiment the height h of CCD camera 101 is estimated on the basis of the premise that the width W of the lane is constant, it will be understood that the width of the lane W may be estimated on the basis of the premise that the height h of CCD camera 101 is constant. Further, although the first embodiment is arranged to calculate the road parameter by using the Kalman filter, the present invention is not limited to this embodiment and may be arranged to calculate the road parameter by using the other estimating method or identifying method such as the least square method.

Returning to Fig. 2, at step S209, processor 100 stores the new road parameter calculated at step S208 in the data storage region of the storage device of road model parameter calculating section 105. The stored road parameter is used in the next image processing including the setting of the lane marker detection areas, the calculation of the deviation, and the calculation of the

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new road parameter. Thereafter, the routine returns to step S203 wherein a new image for the next processing is picked up.

[Second Embodiment]

5 The lane recognition apparatus 1 of a second embodiment comprises basic elements as shown in Fig. 1, as is similar to the first embodiment.

Fig. 3 is a flow chart showing a flow of processes in the second embodiment according to the present
10 invention. First, lane recognition apparatus 1 is started when a switch is operated by the driver or the vehicle is ignited at step S301. Next, at step S302 road parameters for recognizing the shape of a road ahead of the vehicle are initialized, and a content of a counter
15 CNTR is reset (CNTR=0). The definition of the road parameter in the second embodiment is the same as that in the first embodiment.

Steps S303 through S307 correspond to steps S203 through S207 of the first embodiment. More specifically,
20 at step S303 pre-processing section 102 of processor 100 receives the signal of the signal of the image picked up by CCD camera 101, and executes the pre-processing. At step S304 processor 100 sets the small areas in order to detect a lane marker which indicates the lane in which
25 the vehicle is traveling on the screen. At step S305, processor 100 detects a straight line, which most likely seems to be a boundary between the lane marker and the road surface in the region in the small areas set in step S304, and determines the point on the straight line is
30 determined as a lane marker candidate point. Further, at step S306 processor 100 calculates a deviation of the lane marker candidate point detected at step S305 relative to the road model estimated from the result of

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the previous lane marker recognition result. Furthermore, at step S307, processor 100 determines whether or not it is possible to detect the lane marker from the inputted image on the basis of the average deviation p calculated at step S306. That is, marker detection feasibility determining section 107 of processor 100 determines whether or not the road image can be employed for detecting the lane marker.

When it is determined at step S307 that it is possible to detect the lane marker from the inputted image, the routine proceeds to step S308 wherein the content of counter CNTR is set at zero (CNTR=0).

At step S309 following the execution of step S308, processor 100 calculates parameters of the road model from the position of the lane marker candidate points on the image obtained at step S305 as is similar to the processing of step S208 of the first embodiment. Further, at step S310, processor 100 updates the road parameter, that is, stores the new road parameter calculated at step S309 in the data storage region of the storage device of road model parameter calculating section 105 as is similar to the processing of step S209 of the first embodiment.

When the determination at step S307 is negative, that is, when it is determined that it is not possible to detect the lane marker from the inputted image, the program jumps to step S311 wherein the content of counter CNTR is incremented by 1 (CNTR+1→CNTR).

At step S312 following the execution of step S311, it is determined whether or not the content of counter CNTR is smaller than a predetermined value N . When the determination at step S312 is affirmative (CNTR< N), the program returns to step S303 wherein the next image

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processing is executed without updating the road parameter. When the determination at step S312 is negative ($CNTR \geq N$), the program returns to step S302 wherein the initialization of the road parameter and the reset of counter CNTR are executed again.

[Third Embodiment]

The lane recognition apparatus 1 of a third embodiment comprises basic elements as shown in Fig. 1, as is similar to the first embodiment.

Fig. 4 is a flowchart showing a flow of processes in the third embodiment according to the present invention. First, lane recognition apparatus 1 is started when a switch is operated by the driver or the vehicle is ignited at step S401. Next, at step S402 road parameters for recognizing the shape of a road ahead of the vehicle are initialized, and a content of a counter CNTR is reset ($CNTR=0$). The definition of the road parameter in the third embodiment is the same as that in the first embodiment.

Steps S403 through S407 are basically similar to steps S203 through S207 of the first embodiment. More specifically, at step S403 pre-processing section 102 of processor 100 receives the signal of the signal of the image picked up by CCD camera 101, and executes the pre-processing is executed. At step S404, processor 100 sets the small areas in order to detect a lane marker which indicates the lane in which the vehicle is traveling on the screen. At step S405, processor 100 detects a straight line, which most likely seems to be a boundary between the lane marker and the road surface in the region in the small areas set in step S404, and determines the point on the straight line is determined as a lane marker candidate point. Further, at step S406

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processor 100 calculates a deviation of the lane marker candidate point detected at step S405 relative to the road model estimated from the result of the previous lane marker recognition result. Furthermore, at step S407,
5 processor 100 determines whether or not it is possible to detect the lane marker from the inputted image on the basis of the deviation p calculated at step S406.

When it is determined at step S407 that it is possible to detect the lane marker from the inputted
10 image, the routine proceeds to step S408 wherein the content of counter CNTR is set at zero (CNTR=0).

At step S409 following the execution of step S408, processor 100 calculates parameters of the road model from the position of the lane marker candidate points on
15 the image as is similar to the processing of step S208 of the first embodiment. Further, at step S410, processor 100 stores the new road parameter calculated at step S409 in the data storage region of the storage device of road model parameter calculating section 105 as is similar to
20 the processing of step S209 of the first embodiment.

When the determination at step S407 is negative, that is, when it is determined that it is not possible to detect the lane marker from the inputted image, the program jumps to step S411 wherein the content of counter
25 CNTR is incremented by 1 (CNTR+1→CNTR).

At step S412, it is determined whether or not the content of counter CNTR is greater than a predetermined value N . When the determination at step S412 is affirmative (CNTR> N), the program proceeds to step S413
30 wherein the road parameter is estimated using a sequential-type estimator such as the Kalman filter and on the basis of the changing state of the road parameter until the previous processing without using the present

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parameter candidate point. When the determination at
step S412 is negative ($CNTR \leq N$), the program returns to
step S402 wherein the initialization of the road
parameter and the reset of counter CNTR are executed
5 again.

With the thus arranged embodiments according to the
present invention, it becomes possible to eliminate wrong
recognition caused by the incorrect detection of the lane
marker candidate points. Further, it becomes possible to
10 improve the reliability of the lane marker detection
result to the diagnosis of the wrong recognition.
Furthermore, it is possible to convert the offset
quantity of the pixels of the image into the offset
quantity on the road surface. The embodiments according
15 to the present invention is arranged such that when the
image is determined that it is not proper to employ for
detecting the lane marker, the detection result of the
lane marker candidate points obtained from the improper
image are not used to calculate the road model parameter.
20 Accordingly, this arrangement prevents the road shape of
the road ahead of the host vehicle from being incorrectly
detected.

This application is based on a prior Japanese Patent
Application No. 2000-397747. The entire contents of a
25 Japanese Patent Application No. 2000-397747 with a filing
date of December 27, 2000 are hereby incorporated by
reference.

Although the invention has been described above by
reference to certain embodiments of the invention, the
30 invention is not limited to the embodiments described
above. Modifications and variations of the embodiments
described above will occur to those skilled in the art in

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light of the above teachings. The scope of the invention is defined with reference to the following claims.